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**SYSTEM AND METHOD FOR
INDEPENDENT POWER SEQUENCING OF INTEGRATED CIRCUITS**

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CROSS REFERENCE TO RELATED APPLICATION

This application claims the benefit of Provisional Application No. 60/141,393 filed June 29, 1999, the contents of which is hereby incorporated by reference.

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BACKGROUND OF THE INVENTION

Power Sequencing circuits play a key role in a number of applications which require a controlled application of power sources, such as computer systems, and the like. In an integrated circuit having interconnected circuitry that is powered by differing voltages, a power sequencing circuit might be used to control the application of power supply voltages to the various circuits in an orderly manner. In interconnected circuits that operate on differing voltages the circuit operating at the lower voltages tend to be the more susceptible to damage.

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Alternatively, power sequencing circuits are advantageously designed to protect circuits by utilizing a circuit configuration that avoids the turn on of parasitic circuit elements that tend to damage integrated circuitry.

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Those having skill in the art will understand the desirability of having a power sequencing circuit that controls power supply application and tends to prevent the creation of parasitic current paths. This type of device would necessarily provide power supply sequencing and integrated circuit damage protection by providing a circuit to control the application of power supply voltages in an integrated circuit and is coupled to the integrated circuit such that parasitic current paths tend to be eliminated, thus allowing an integrated circuit comprising individual circuits operating from differing voltages to be produced.

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SUMMARY OF THE INVENTION

There is therefore provided in a present embodiment of the invention a circuit for applying power to mixed mode integrated circuits in a predefined sequence to a first circuit powered by a first voltage and a second circuit powered by a second voltage that is less than the first voltage and having the second voltage coupled to the first circuit. The circuit for applying power to mixed mode integrated circuits includes, a modified IO cell of the second circuit. The modified IO cell has a driver transistor including a back gate terminal, a gate terminal that is driven by the second circuit, a source terminal that is coupled to a first circuit signal, and a drain terminal that is coupled to the second power supply.

The circuit for applying power to mixed mode integrated circuits further includes, a controller circuit coupled to the first voltage and the second voltage supplied as controller circuit inputs. The controller circuit has a plurality of controller circuit outputs.

The circuit for applying power to mixed mode integrated circuits also includes, a back gate bias application circuit. The back gate bias application circuit has a plurality of inputs coupled to the plurality of controller circuit outputs, and an output coupled to the backgate of the driver transistor backgate terminal.

Many of the attendant features of this invention will be more readily appreciated as the same becomes better understood by reference to the following detailed description considered in connection with the accompanying drawings.

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DESCRIPTION OF THE DRAWINGS

5 These and other features and advantages of the present invention will be better understood from the following detailed description read in light of the accompanying drawings, wherein:

FIG. 1 is a schematic diagram illustrating parasitic current flow from higher voltage power supply V_{HIGH} to a lower voltage power supply V_{LOW} at power supply turn on;

10 FIG. 2 is a schematic of an embodiment of a circuit that prevents the turn-on of the parasitic diode present in the transistor by an incoming signal having a higher voltage level;

FIG. 3 is a schematic of a second embodiment of the invention that allows independent sequencing of the power
15 supplies;

FIG. 4 is a schematic diagram of a control circuit that evaluates power supply status and generates a required set of control signals;

20 FIG. 5 is a graph of the relationship of the voltages used in the power sequencing circuit;

FIG. 6 is a schematic diagram of an embodiment of a bias generator circuit; and

FIG. 7 is a block diagram of a system that allows interconnected circuits operating from differing power supplies
25 to be protected from damage caused by variations in sequential power supply application at circuit power up.

Like reference numerals are used to designate like parts in the accompanying drawings.

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DETAILED DESCRIPTION OF THE INVENTION

FIG. 1 is a schematic diagram illustrating possible parasitic current flow from higher voltage power supply V_{HIGH} to a lower voltage power supply V_{LOW} at power supply turn on. A trend in integrated circuit design is to operate integrated circuits at lower power supply voltages. Low voltage power supply operation is desirable to reduce power dissipation and to allow fast circuit technologies to operate without breakdown voltage problems. If power supplies of differing voltages are present in a circuit, these power supplies do not reach their final value of voltage at the same time when they are activated. Also, if circuits 102, 104 operate from different power supply voltages, V_{LOW} V_{HIGH} , The components within the circuit tend not to rise to their final operating voltage at the same time tending to cause an undesired current flow 106.

One or more low voltage integrated circuits ("ICs"), such as low voltage integrated circuit 102 operates from one or more low voltage power supplies such as V_{LOW} . One or more high voltage integrated circuits, such as high voltage integrated circuit 104 that operates from one or more higher voltage power supplies such as power supply voltage V_{HIGH} . The one or more high voltage power supplies are at a higher potential than V_{LOW} . The two integrated circuits 102, 104 include individual substrates 122, 124 and operate in conjunction with each other in a common functional environment 108, such as a common semiconductor substrate, printed circuit board, ceramic hybrid substrate, or the like to provide an overall desired circuit function.

The two circuits, and thus the power supplies V_{HIGH} and V_{LOW} , are typically coupled electrically by one or more interfacial connections such as shown 115. Often circuits that operate from different potentials are present to achieve a given an overall desired circuit function. It is sometimes desirable to mix the circuits operating from different power supplies if lower power

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consumption can be achieved by utilizing one or more available circuits that operate from lower power supply voltages.

5 A situation where this would arise is in the use of pre-designed intellectual property ("IP") cores, where because of time or budget constraints it is desirable to use the circuit as it was designed, without modifying it to operate from a common power supply voltage.

10 Interfacial connections are typically achieved in integrated circuits through one or more pads 116. The pads are typically coupled to a pin or lead of an integrated circuit package, or to chip carrier, via a wire bond. Current flow path 106 to the lower voltage power supply from the high voltage power supply is
15 typically through one or more parasitic diodes, such as D2, present in a transistor M1. The parasitic diodes tend to be inherent to the internal circuitry of an integrated circuit ("IC") 102 operating from the lower supply voltage V_{LOW} . A common path for current flow to the lower voltage power supply is
20 through interface circuitry M1 present at an integrated circuit pin. For example, in digital circuitry interfacial circuitry of this type is often utilized to mix different logic families such as TTL, LS and CMOS. Additionally, digital circuitry often incorporates open collector transistor outputs into the designs
25 as interfacial circuitry to provide sufficient and adjustable drive levels to circuitry coupled to these outputs.

Current flow 106 from the higher voltage power supply V_{HIGH} to the lower voltage power supply V_{LOW} typically occurs on power up through a transistor M1 in an integrated circuit 102 that is
30 coupled to a circuit 104 operating from a bias voltage higher than that of the transistor. The individual integrated circuits are often disposed on a common substrate. The difference in turn on times of the different power supplies V_{HIGH} , V_{LOW} , or the differences in time that it takes for various components in a
35 given integrated circuit to migrate or float up to a final

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voltage is often enough to turn on a parasitic or ESD device
inherent to the circuit operating from the lower power supply
5 voltage.

In summary, circuit 102 is operated from the lower voltage
supply V_{LOW} and can be damaged by parasitic or ESD device turn-on
caused by coupling to the circuit 104 that is operated from the
higher supply voltage V_{HIGH} . The connection 115 coupling the two
10 circuits provides a low impedance path between the higher voltage
power supply and the lower voltage power supply through a
parasitic device. A current path 106, through a parasitic diode,
such as D2, that couples supply V_{LOW} and V_{HIGH} is established. It
is desirable to modify the connections to driver or interfacial
15 transistors, such as M1 in the low voltage integrated circuit 102
to eliminate the current path 106.

FIG. 2 is a schematic of an embodiment of a circuit that
prevents the turn-on of the parasitic diode present in the
transistor by an incoming signal from a circuit operating at a
20 higher voltage level. The technique requires that a connection
to the higher voltage 120 is available on the integrated circuit
102. The higher voltage V_{HIGH} is tied to a backgate 103 of one or
more of the interfacial driver transistors M1 that tend to be
prone to parasitic turn on.

25 A backgate connection refers to a gate connection that
includes the entire substrate of the integrated circuit. When
a backgate has a higher potential, parasitic diodes D1 and D2 do
not turn on, preventing a large current flow, that would
otherwise tend to damage the ICs. In a typical integrated
30 circuit a gate contact is disposed as a metalized pattern on the
surface of an IC directly above a channel region of a field
effect transistor. Typically, there is an insulating layer
between the gate contact and the channel region. A backgate
connection consists of adding a contact to the substrate of the

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integrated circuit, that is on the opposite side of the integrated circuit from the gate contact.

5 The coupling of a backgate contact to the substrate is established through to an upper surface of the wafer upon which the circuit is disposed. The backgate contact is coupled to the polysilicon substrate through a diffusion window disposed in the integrated circuit.

10 In using the described circuit, the higher voltage power supply is properly applied before the lower voltage power supply is applied. If the power is not sequenced from highest voltage to lowest voltage, the circuit in which the embodiment of the protection circuit is applied tends to be prone to damage. The
15 application sequence described, and circuitry to implement it, may tend to be undesirable for some circuit applications. It is desirable to utilize the circuit shown in FIG. 2 and additional circuitry that will allow the power supplies to be properly sequenced on without regard to the order of application of the
20 power supplies.

One or more integrated circuit IP cores 102 are powered by one or more low bias voltages, such as V_{LOW} . The low bias voltages are less than one or more high bias voltages, such as V_{HIGH} . The low bias voltages are coupled to one or more low
25 voltage integrated circuit IP cores 102, present on the integrated circuit 108. The high bias voltages are coupled to one or more high voltage integrated circuit IP cores 104 present on the integrated circuit 108. Coupling of a bias voltage to an IP core may be through a pad, pin or other equivalent connection.

30 Although the embodiments of the invention are presented in the context of integrated circuits, it will be appreciated by those skilled in the art that the invention also applies to technologies such as individual packaged integrated circuits that are disposed on one or more printed wiring boards that require
35 differing supply voltages. Equivalently the invention may also

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be applied to circuitry biased by differing power supplies that require power sequencing to function properly, whether the circuitry is disposed on an integrated circuit, printed circuit board or the like. Bias voltages V_{HIGH} and V_{LOW} are shown as being supplied externally. Equivalently, either V_{HIGH} and/or V_{LOW} may be generated on the integrated circuit from one or more voltages available locally.

10 Circuit 102 is shown as having an I/O cell or interfacial circuit 122. Integrated circuits typically interfacial circuitry 122 at each I/O connection 116. The I/O cell is connected to external voltages V_{LOW} , V_{HIGH} and to one or more external signal connections, such as shown at 115. The external signal typically originates from another circuit 104 that is operating at the same or higher voltage. Voltages V_{LOW} and V_{HIGH} are supplied as supply voltage rails within the I/O cell.

As shown, an incoming signal 115 to the low voltage circuit 102 is coupled to a driver transistor M1 at its source. A drain of M1 is coupled to a low power supply rail. A back gate of transistor M1 is coupled to the higher voltage power supply, V_{HIGH} at pin 120.

A parasitic diode D1 tends to be present between the drain and the back gate of M1. A parasitic diode D2 also tends to be present between the back gate and source of M1. A gate of M1 is being driven by internal circuitry of the I/O cell. Although this circuit tends to be more robust, as previously mentioned, severe damage tends to occur if the system power supply is activated first. In some applications, a need for power supply sequencing tends to be undesirable. It is desirable to provide over voltage protection as described in FIG. 2 and additional circuitry that provides independent sequencing of the power supplies.

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FIG. 3 is a schematic of an embodiment of the invention that tends to provide independent sequencing of the power supplies and parasitic current flow. Power supply status is evaluated by a controller circuit 110 to generate a set of control signals B1, B2 utilized by the I/O circuitry (122 of FIG. 2) to sequence the power supplies without damaging the IP core. The circuit of FIG. 2 is modified by the addition of two transistors that function as switches, MB1, MB2 and a controller circuit 110. Transistors MB1 and MB2 prevent the back gate of M1 from being connected to the supplier voltage system power supply before the system power supply is available at its full voltage. Transistors MB1 and MB2 are controlled via gate signals B1 and B2 that are supplied by controller circuit 110.

The source of driver transistor M1 is coupled to an I/O signal 115 (of FIG. 2) at a pad 116. The drain of M1 is coupled to the low voltage supply rail set at voltage V_{LOW} . The back gate of driver transistor M1 is coupled in common to the sources and back gates of transistors MB1 and MB2. The drain of MB1 is coupled to the system power supply line set at a voltage value V_{LOW} . Transistor MB2 is coupled to a chip power supply set at a value of V_{HIGH} .

Controller circuit 110 provides gate signals B1, B2 to the gates of MB1 and MB2 respectively. The controller circuit is coupled to voltage supplies V_{LOW} and V_{HIGH} . Gate signals B1 and B2 control transistors MB1 and MB2 to prevent system power from being coupled to the back gate of M1 when the chip power supply is present before the system power supply.

FIG. 4 is a schematic diagram of controller circuit 110 that evaluates power supply status and generates a required set of control signals utilized by the circuit of FIG. 3. The controller circuit 110 makes a decision based upon which power supply is activated before the other by using a comparator 112. Comparison is made based upon reference voltages derived from

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voltages present for the chip power supply and the system power supply.

5 From the power supplies, reference voltages V1 and V2 are created as inputs coupled to the comparator 112. The comparator output is fed to a bias generator 114 that generates the gate signals B1 and B2. The relationship between voltages B1 and B2 is such that they allow either MB1 or MB2 to turn on, but do not
10 allow MB1 and MB2 to turn on simultaneously. Note that in an embodiment, MB1 and MB2 may be on simultaneously for a small period of time when the power supply values are rising faster than B1 and B2 can correct MB1 and MB2. In the exemplary embodiment, momentary overlap is minimal and is not as
15 destructive as the case where the power sequencing circuit is absent. To drive the control signals B1 and B2, the comparator 112 takes a reading based upon the state of each power supply. Comparator inputs are voltages V1 and V2.

Voltage V1 is generated when the lower voltage chip power
20 supply begins to ramp up in voltage value. When the chip power supply begins to supply voltage to the circuit, a current source I, starts current conduction through a chain of diodes DS. The diode chain DS provides the voltage drop V1. Voltage V1 provides an indication of the chip power supply reaching a given
25 level. Voltage V1 is coupled to a negative terminal of the comparator U1.

Voltage V2 is the output of the resistive divider comprising resistors R1 and R2. Voltage V2 is the reference voltage that sets a trip point which causes a comparator output of U1 to
30 change state. Resistor R1 has a first terminal that is coupled to the systems power supply line and a second terminal that is coupled to a first terminal of R2 and the positive input of the comparator U1. The second terminal of R2 is coupled to ground. The output of the comparator U1 is coupled to a bias generator
35 circuit 114.

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The bias generator circuit 114 had inputs including the comparator input, V_{HIGH} and V_{LOW} . Bias generator outputs are
5 voltages B1 and B2.

FIG. 5 is a graph of the relationship of the voltages used in the power sequencing circuit of FIG. 3. At turn on and prior to the comparator (U1 of FIG. 4) changing state 140 V_{LOW} is applied to the backgate of a driver transistor (M1 of FIG. 3) in
10 the interfacial circuit of the low voltage circuit (102 of FIG.3). During time interval 140 the voltage on the gate of MB2 of FIG. 3 is close to V_{LOW} , turning off MB2 and preventing the rising voltage of V_{HIGH} from being applied to the backgate of M1 (of FIG. 3). Also during the time interval 140 the voltage B1
15 applied to the gate of MB1 of FIG.3 is close to or equal to zero volts coupling V_{LOW} to the backgate of M1 of FIG. 3.

When the comparator changes state 136, the levels of B1 and B2 change state. The comparator change of state is set so that it is somewhat lower than the chip power supply to avoid noise
20 tending to trigger the transistor switches (MB1 and MB2 of FIG. 3).

During time interval 142 the levels of B1 and B2 (of FIG. 3) change state causing V_{HIGH} to be applied to the backgate of a driver transistor (M1 of FIG. 3) in the interfacial circuit of
25 the low voltage circuit (102 of FIG.3). During time interval 140 the voltage on the gate of MB2 of FIG. 3 is reduced to a level below V_{LOW} , turning on MB2 and applying V_{HIGH} to the backgate of M1 (of FIG. 3). Also during the time interval 142 the voltage B1 applied to the gate of MB1 of FIG.3 is rising as the voltage of
30 V_{HIGH} rises causing transistor switch MB1 (of FIG. 3) to turn off decoupling V_{LOW} from the backgate of M1 of FIG. 3. The voltage V_{HIGH} on the backgate of M1 continues to rise as V_{HIGH} ramps up to its final value.

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FIG. 6 is a schematic diagram of an embodiment of a bias generator circuit 114. The bias generator circuit 114 includes 3 inverting circuits 130, 132, U2. The inverter circuits produce outputs levels B1 and B2 in response to the comparator output and the power supply voltages V_{HIGH} and V_{LOW} that tend to change on power up of a system. Outputs B1 and B2 are as shown in FIG. 5 and control the application of V_{LOW} and V_{HIGH} to a backgate of a driver transistor in an interfacial circuit.

Signals B1 and B2 do not function as conventional inverter signals that switch between power supply rails and ground. Inverter U2 is a conventionally constructed as known by those skilled in the art.

A modified inverter for B2 logic levels 130 includes a PMOS transistor Q1 and an NMOS transistor Q3 to achieve an inverter function. The modified inverter 130 functions as a conventional inverter before the comparator changes state (140 of FIG. 5), B2 follows the level of V_{LOW} as a high state. After the comparator changes state 142, B2 changes to a low state. However, this low state does not correspond to zero volts, but to an intermediate value less than V_{LOW} . Transistors Q2 and Q4 are configured as diode level shifters and prevent B2 from floating all the way to ground when the comparator changes state. A sufficient level is chosen for B2 that will not over stress the gate of the transistor it is driving (MB2 of FIG. 3) by applying an excessive gate to drain voltage. Conventionally constructed current source I2 is present in the circuit to provide bias for the transistors configured to function as diodes Q2, Q4.

A modified inverter for B1 logic levels 132 includes a PMOS transistor Q5 and two NMOS transistors Q6, Q7 to achieve an inverter function. Transistors Q6 and Q7 are required due to the high bias voltage V_{HIGH} being present. Transistor Q6 provides a voltage drop to prevent transistor Q7 of the inverter from being over stressed.

In the bias generator circuit 114 the inverter U2 is coupled to the V_{LOW} power supply. The inverter input terminal is coupled to the output terminal from the comparator (U1 of FIG. 4). The inverter output terminal is coupled to a gate of Q1.

A modified inverter for B2 logic levels 130 includes a PMOS transistor Q1 and PMOS transistors Q2, Q3, and Q4. Transistor Q1 includes a source terminal coupled to V_{LOW} , a backgate terminal coupled to V_{LOW} , a drain terminal coupled to output B2, and coupled to a drain terminal of Q2. A conventional current source I2 has a input terminal coupled to V_{LOW} , and an output terminal coupled to the source of Q2.

Transistor Q2 includes a gate terminal coupled to B2, a backgate terminal coupled to a ground, and a source terminal coupled to a drain terminal of Q3. Transistor Q3 includes a gate terminal coupled to the gate terminal of Q1, a backgate terminal coupled to ground, and a source terminal coupled to a drain terminal of Q4. Transistor Q4 includes a gate terminal coupled to the drain terminal of Q3, a backgate terminal coupled to ground and a source terminal coupled to ground.

A modified inverter for B1 logic levels 132 includes a PMOS transistor Q5, and NMOS transistors Q6 and Q7. Transistor Q5 includes a source terminal coupled to V_{HIGH} , a gate terminal coupled to B2, a backgate terminal coupled to V_{HIGH} and a drain coupled to terminal B1.

Transistor Q6 includes a drain terminal coupled to terminal B1, a gate terminal coupled to the input of inverter U2, a backgate terminal coupled to ground and a source terminal coupled to a drain of Q7. Transistor Q7 includes a gate terminal coupled to the input of inverter U2, a backgate terminal coupled to ground and a source terminal coupled to ground.

FIG. 7 is a block diagram of a system that allows interconnected circuits operating from differing power supplies to be protected from damage caused by variations in sequential

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power supply application at circuit power up. The embodiment described is implemented as an integrated circuit. However, those skilled in the art will appreciate that the system described may be applied to other configurations of circuitry, such as printed wiring boards, hybrid circuits and the like.

An integrated circuit 108 utilizes a number of sub circuits, often referred to as IP cores ("cores") 102, 104 to implement a desired overall function. Each of the IP cores might implement an individual sub-function such as a memory, processor, modulator or the like. Examples of overall functions might include the implementation of a cable modem or G-Bit Ethernet device. IP cores often operate from differing voltages depending upon the technology used in designing the IP cores, or other considerations. The cores are coupled to each other to realize the overall function desired.

IP cores 102 104 are often interconnected so that an I/O connection exists between a first IP core 102, and a second IP core 104. IP core 104 is biased by a voltage V_{LOW} , that is lower in value than the bias voltage applied to the second IP core, V_{HIGH} .

Lack of power sequencing at start up tends to damage an IP core 102 operating from the lower power supply voltage. By utilizing power sequencing circuitry 128 and a back gate connection to transistors such as PMOS transistor M1 disposed in the I/O circuitry of the lower voltage cores 102, damage to the circuitry tends to be reduced when improper sequencing of the power supplies 126 occurs.

In the embodiment shown several low voltage circuits or "cores" 102, are disposed on an integrated circuit substrate 108. In addition one or more cores that operate at higher voltages 104 are present on the substrate and functionally interact with the low voltage circuits or "cores".

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Interconnection between cores typically is accomplished through interfacial (or I/O) circuits. Interfacial circuits typically include transistors such as M1 that are disposed between the circuitry on the IP core and one of "n" incoming signal lines. A back gate connection is provided from the interfacial transistor to the power sequencing circuitry 128. In addition a connection from the power supply V_{HIGH} is supplied to the circuit running off of the lower supply voltage V_{LOW} . The higher supply voltage is utilized to operate transistor M1 of the interfacial circuitry in a manner tending to reduce damage caused by variations in power sequencing.

Power supply voltages V_{HIGH} and V_{LOW} emanating from power supply circuitry 126 are also processed by the power sequencing circuitry 128. PMOS transistors MB1 and MB2 operating under the control of a controller circuit 110 control the application of V_{HIGH} and V_{LOW} to the interfacial circuits such that the circuitry is not damaged if the power supplies are sequenced randomly, or if one supply does not rise to its final value as quickly as expected.

The circuitry shown in the block diagrams may be equivalently shifted between the functional blocks described in the practical implementation of the invention. In particular the interfacial circuitry may be merged into the power sequencing circuitry block.

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